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FIFTEEN YEARS OF INVESTIGATIONS BY THE LABORATORIES OF THE METROPOLITAN WATER BOARD[1]

By Melville C. Whipple[2]

The principal sources of London water are three rivers—the Thames, the Lee, and the New, all of which are polluted and require purification by storage, filtration, chlorination, or a combination of these processes. Control of raw sources, operation of purification works, and proper regard for the physical, chemical, and bacteriological quality of the water delivered to consumers all demand laboratory facilities, and in the case of a system as large as that of London they involve a large amount of analytical work. It is now sixteen years since the laboratories of the Metropolitan Water Board were established to take care of such demands, and at their head, as Director of Water Examination, has been a man widely and favorably known in the United States, Sir Alexander Houston.

The routine of these laboratories involves annually an examination of nearly 13,000 samples, a large task in itself, and one which has been an important factor in the maintenance of a typhoid fever rate of 1.7 per 100,000 in the years before the war. In addition, a large amount of research has been conducted upon problems having to do with the quality and purification of water and technical procedures in the laboratory. Much of this has been fundamental in character and the results have been used the world over to advance the art of water purification and our understanding of quality changes. These contributions rate the London laboratories among the foremost in general usefulness to all men engaged in water purification problems.

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[1] A review of fifteen years of experience of the laboratories controlling the water supplies of Greater London. Prepared at the request of the Editor, not only in order to record the results of experiments for our readers, but to illustrate the possibilities of contributions to water supply study which only too frequently are neglected by many administrative water boards.

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Ready access to all this work has been made possible through a liberal policy of publication. A series of monthly reports since November 1905 has formed a part of the Government Water Examiner's Monthly Report on the Metropolitan Water Supply, and these have been followed since March 31, 1907, by fifteen Annual Reports on the quality of London waters and thirteen Reports on Research Work, both compiled by Sir Alexander Houston. The Annual and Research Reports have been exhaustive and complete in the presentation of data. The discussions and conclusions have been admirably presented in a logical and forceful manner. In fact, these reports occupy a place in waterworks literature unique in themselves, and for this reason have always been awaited with interest and admiration on the part of those who were fortunate enough to receive them.

It has always been a matter of regret to the writer that much of the best work done by American waterworks laboratories has been made useless to all but a very few through a lack of proper publication. Some of it has never been published owing to perverted policies of economy in printing, some has been presented in a fragmentary way through the medium of short professional papers, and a great deal has been presented in a weak and "dry" manner. Our larger laboratories would do well to adopt some method of issuing at least occasional reports of research or routine work which merits the use of imagination and a convincing manner of presentment.

In his Fifteenth Annual Report for the year ending March 31, 1921, Sir Alexander has taken occasion to review some of the investigations carried out under his direction, touching the high lights of achievements in the fifteen-year period. It is perhaps worth while to recall in brief fashion the results of the more important studies.

VITALITY OF TYPHOID BACILLUS IN WATER

In the First, Sixth, Seventh, and Tenth Research Reports experiments are described bearing on the vitality of B. typhosus in water. The findings are now classic and are quoted wherever the subject comes under discussion. The first studies were made upon cultivated strains of laboratory cultures. These were inoculated into river water and the number of surviving organisms determined from time to time. Over 99 per cent of the original number, whether large or small, succumbed in the first week. A few survived for five to eight weeks, forming the group often spoken of now as the "resistant minority." Their significance has been a subject for much discussion, but general opinion supports the conclusion that four weeks' storage provides a reasonable margin of safety. These investigations were undertaken with special reference to the storage of polluted waters, which is widely practiced in England.

Later experiments were made with uncultivated typhoid bacilli taken directly from their parasitic existence and introduced into water, just as they are under natural conditions of spreading infection. These died much more quickly than the laboratory strains, and this was the case in both laboratory and outdoor experiments in tanks holding 350 gallons of river water.

A most important phase of these studies was the effect of temperature. At 50° F., and above, the initial rapid drop in numbers took place in the first week as noted, but, at 41°, one to two weeks were required and near the freezing point from two to three weeks. Assuming that a reduction from 100,000 typhoid bacilli per cubic centimeter to 3 per cubic centimeter represents practical sterility, Sir Alexander concluded that this result can be reached by

5 weeks' storage at 32.0° F.
4 weeks' storage at 41.0° F.
3 weeks' storage at 50.0° F.
2 weeks' storage at 64.4° F.

All of this work brought out clearly the great purifying influence of adequate storage upon contaminated waters; it also demonstrated the fortunate fact that the greatest natural protection is afforded during and immediately preceding those months when the incidence of typhoid fever is highest, namely, during the late summer and fall. On the other hand, it emphasized the added significance of the presence of infective material in water during the cold months of the year when destructive influences are less marked and when sudden increases in flow tend to shorten the period of travel from watersheds through reservoirs, and to the consumer.

THE CHOLERA VIBRIO AND TESTS FOR ITS IDENTIFICATION

Cholera may be a water-borne disease, although it has given in recent times little cause for worry in northern temperate countries, largely through the vigilance of health authorities who have prevented its becoming endemic by control measures at ports of entry. Nevertheless, there is a possibility that this protection may not always be maintained, and for this reason the work dealt with in the Fourth, Fifth, Eleventh, and Twelfth Research Reports on the cholera vibrio in river waters represents a reserve of scientific knowledge which may be drawn upon in any emergency. Already it must have found application in warmer countries where cholera is endemic.

As in the case of the typhoid bacillus, storage of infected water was found to accomplish a rapid and great reduction in the number of cholera vibrios, 99.9 per cent after one week. After three weeks the cholera vibrio could not be isolated in 100 cc. of water. The protection afforded against this pathogenic organism was, then, equally as great as in the case of B. typhosus. The reports of the cholera vibrio experiments show that this microbe can be isolated from raw river water even when present in small numbers. One of its chief characteristics is the production of the cholera-red reaction in peptone broth when sulphuric acid is added to 37° cultures of 24 to 40 hours' growth.

The immense amount of work done in these laboratories on certain problems is well exemplified by the study of the reliability of the cholera-red reaction in excluding harmless water bacteria. Some 2400 samples were examined and 6000 colonies isolated. Only 3 per cent of these gave a provisional or presumptive test by the cholera-red reaction, and none of them answered the true cholera standard when final confirmatory tests were made. The conclusion was that there is no danger of reporting the cholera vibrio present in non-infected waters if suitable tests are made.

SEARCH FOR SPECIFIC DISEASE ORGANISMS IN RAW WATERS

One of the most extensive and laborious pieces of research reported during the fifteen years was that involving the search for specific microbes of water-borne diseases in polluted river waters. Details of the experiments are given in the Second, Fifth, Seventh. Ninth, and Tenth Research Reports. The first work, in 1908, involved a study of 7329 microbes from 156 samples of raw river water. Not one of these proved to be B. typhosus.

A very important fact to be established in this connection was the delicacy of such tests—that is, a knowledge of the smallest amount of water that could be expected to give a positive result in the presence of the organisms. This was done by a system of *comparative* examinations in which the raw Thames and Lee samples to be examined were divided into two portions, one of which was inoculated with a pure culture of the organism. Both portions were then examined quantitatively. Out of 22, 141 sub-cultures from river water not one proved to be B. typhosus or B. enteritidis (Gärtner's bacillus). Three colonies were classed as doubtful, two of them as B. typhosus. By dividing the average number of specific organisms recovered from the whole of the inoculated portions by the average number of specific organisms per cubic centimeter which were originally added, there was obtained an inferential index of the amount of water which might be expected to contain one organism and so give a positive result. Under the conditions of these experiments B. typhosus, from this index, could have been detected in the river water, if present, to the extent of 1 in 9 cc., and B. enteritidis, 1 in 19 cc.

Using these figures for the raw water and concluding from results of six years' (1906–1911) treatment of the River Thames water that the "microbial badness" was reduced 1000 times before reaching the consumer, as shown by B. coli tests, the conclusion of Sir Alexander was that there were good grounds for the assumption that B. typhosus was not normally present in tap water in the proportion of 1 per 9000 cc., nor Gärtner's bacillus in the proportion of 1 per 19,000 cc.

These and other deductions from a mass of experimental data serve to indicate how facts which seem to possess only scientific interest can be given practical significance in the hands of a competent and careful interpreter.

STUDIES OF STREPTOCOCCI

Many water analysts will remember the controversy which was waged some ten years ago in regard to the presence and significance of streptococci in water. Many media were devised for their cultivation, but most of them have fallen into disuse and the presence or absence of streptococci is now seldom sought.

The Laboratories of the Metropolitan Water Board engaged in long and painstaking research on the subject of the bacterial flora of human and animal feces, on the biological characters of different strains of streptococci which were isolated, and on the presence of streptococci in sewage polluted waters, particularly those of the Thames, Lee, and New Rivers. Results of this research are given in the Fifth and Tenth Research Reports and in the Annual Reports of 1908 and 1909. Of passing interest in this connection was the invention of a series of descriptive terms to designate different strains of streptococci. These terms were compounded from cultural attributes of the strains, e.g., "lamirasacal," denoting acid in *la*ctose, clotting in *mi*lk, acid in *ra*ffinose, *sac*charose and *sal*icin media.

The conclusions reached were that human feces usually contain a very large number of streptococci, more than 100,000 per cubic centimeter, although some stools are practically devoid of these forms, that the river waters mentioned contained on the average less than one streptococcus per cubic centimeter, indicating by this test that 10,000 Imperial gallons of water contained less than 1 pound of human feces, and that the chances of any appreciable number of fecal streptococci reaching the consumer of stored and filtered water were very remote. Thus, the tendency of streptococci to succumb rapidly in natural waters renders their use as an index of sewage contamination of little value except to indicate very recent addition of sewage to such waters. Sir Alexander points out the possibility that some fecal forms may be much more resistant, as we know B. coli to be, and that quality must be judged by all factors, physical, chemical, bacteriological, meteorological, and epidemiological. This necessity of weighing all the evidence and of taking the broadest possible view is stressed throughout all his reports and practiced in his writing A recent example of this was his contribution to the Engineering News-Record, September 22, 1921, on "B. Welchii, Gastro-Enteritis and Water Supply," a most able review of the work and divergent opinions on this subject.

BIOLOGICAL CHARACTERS OF B. COLI

The Seventh Research Report devoted space to the results of studies of different varieties of B. coli in raw, stored, and filtered water. Only those types fermenting lactose and forming indol were studied or considered as "standard" B. coli. A table is given on page 47 of the Fifteenth Annual Report which classifies some 26 varieties on the basis of their sugar fermentations, Voges-Proskauer test, etc., some eleven attributes of the different varieties being used for the classification. The actual and relative frequencies of each variety in raw, stored, and filtered water samples are also given.

The conclusions of this work bring forth the futility of attempting to multiply varieties so far as the practical application of the results may go. It was not long ago in this country that water analysts fell victims to this mania of multiplying types merely out of love for the pursuit of pure science. The result was that the greatest confusion reigned in regard to what attributes B. coli ought to be considered as possessing. The B. coli test became discredited and some sought to throw it overboard, even in the absence of anything more satisfactory. The air has cleared since that time, and we have a better understanding of the purpose of such tests; also advances have been made which enable us to separate in most cases fecal forms such as true B. coli from non-fecal forms such as Bact. aerogenes. The work of Winslow and of Rettger and their co-workers is notable in this connection.

The test for sewage contamination of water resolves itself into two phases, the qualitative and the quantitative, of which the latter is of dominant importance, both in measuring fluctuations of quality and in comparing one supply with another. The qualitative phase is cared for by selecting a test which will record any species common to the intestinal flora in large numbers and having a reasonably long life in natural waters—that is, one which is fairly comparable with pathogenic intestinal forms in its resistance to destruction. The B. coli test best answers these requirements.

THE LEATHER BACILLUS

In 1916 an interesting bacteriological problem presented itself to the Board's Laboratories. Tap samples at one place showed the presence of a lactose fermenting, indol positive organism which was not found in neighboring taps. It was eventually shown that the origin of this organism was in the leather washer of the tap, and it was called the leather bacillus. In pure culture it sometimes, but not always, attacked other leather washers in sterile tap water, but not non-leather washers. The "susceptibility" of some washers brought up the possibility that pathogenic bacteria might at times multiply in taps, but experiments demonstrated that the typhoid bacillus, cholera vibrio, and B. coli forms would not multiply under conditions favorable to the leather bacillus. On the other hand, they suffered extinction.

The organism was closely related to B. lactis aerogenes and B. capsulatus, fermenting the same sugars, not changing inulin and dulcite and not liquefying gelatine. It produced indol readily, while the latter two did not, although some workers ascribe indol formation to B. capsulatus and B. lactis aerogenes. Also, laboratory strains of these two organisms multiplied rapidly in some experiments under the same conditions as the leather bacillus. The true identity was not established, but it was concluded that the current quality of a tap water sample could not be judged by the presence of bacteria answering the characteristics of any of these three. They might have established themselves in the washer a long time previously.

STORAGE OF WATER

The use of large reservoirs, as the Staines, Chelsea, and Walthamstow, has done much to relieve London of the odium of continued use of impure sources. Storage has improved every quality of the river waters, physical, chemical, and bacteriological, "so that in a sense it may be said that London derives its supply from large relatively pure artificial lakes."

Storage and its attendant changes have, therefore, always commanded a great deal of attention from the Laboratories of the Water Board. Various studies are described in the Third, Fifth, Tenth, and Twelfth Research Reports and also in those dealing with the destruction of pathogenic bacteria, as the First, Fourth, Sixth, and Seventh Reports.

In view of recent discussions in this country relative to the merits of storage and the advisability of putting faith in stored waters, the conclusions of Sir Alexander Houston on this subject are of considerable interest and are quoted from the Fifteenth Annual Report. They deal with the advantages accruing from storage.

(1) Storage reduces the number of bacteria of all sorts: the number of bacteria capable of growing on "agar" at blood heat; the number of bacteria capable of growing in a bile-salt medium at blood heat, chiefly excremental bacteria.

(2) Storage greatly reduces the number of B. coli. (Tables of results are given.)

(3) Storage, if sufficiently prolonged, devitalises the microbes of water-borne disease (*e.g.*, the typhoid bacillus and the cholera vibrio).

(4) Storage reduces the amount of suspended matter, colour, ammoniacal nitrogen, and oxygen absorbed from permanganate.

(5) Storage usually reduces the hardness and may reduce (or alter the quality of) the albuminoid nitrogen.

(6) Storage alters certain chemical river water ratios; for example, the colour results improve more than the results yielded by the permanganate test.

(7) Storage has a marked 'levelling' effect on the totality of water delivered to the filter beds.

(8) Storage always lengthens the life of the filters unless any undue development of algal or other growths has occurred. For example, at the Southwark and Vauxhall Works the life of the filter beds has been greatly lengthened, leading to a great saving in labour since Walton Reservoir water was used for filtration purposes. On the other hand, it must be admitted that when growths are super-abundant river water (except during floods) filters better than stored water. Photographs of some of these growths are shown in the writer's Eleventh, Twelfth and Thirteenth Annual, and Twelfth and Thirteenth Research Reports.

(9) An adequately stored water is to be regarded as a 'safe' water, and the 'safety change' which has occurred in a stored water can be recognised by appropriate tests.

Some words of explanation are here needed.

It is shown not only that B. coli is usually absent from 10 cc. of the *stored* water, but that it is not infrequently absent from even 100 cubic centimetres. Further, 100 experiments carried out over a period of ten months showed that the B. coli naturally present in the raw water remain, on the average, alive in 10 cc. of the water for a longer period (about 10 days) than would suffice for the elimination of 99 per cent. of any typhoid bacilli, assuming that these were initially present in the *raw* water. The disappearance of the more hardy and robust B. coli from a stored water thus affords presumptive evidence of the strongest kind that a similar fate would have befallen the typhoid bacillus or the cholera vibrio, had these pathogenic microbes been present in the water.

It is also possible by chemical tests to gauge the probable "safety" of a stored water. For example, there are certain ratios which are characteristic of a *raw* water and others equally suggestive of the same water after prolonged storage.

Take the case of the *raw* Lee and *stored* Lee waters as an illustration.

52 samples collected from August 7, 1907 to July 27, 1908, yielded the following average ratios when the (A) ammoniacal nitrogen, (B) colour, (C) colour and (D) turbidity results were in each case divided by the albuminoid nitrogen, albuminoid nitrogen, permanganate and albuminoid nitrogen results, respectively.

$\frac{\text{FREE}}{\text{ALBUMINOID}}$ (A)		$\frac{\text{COLOUR}}{\text{ALBUMINOID}}$ (B)		$\frac{\text{COLOUR}}{\text{PERMANGANATE}}$ (C)		$\frac{\text{TURBIDITY}}{\text{ALBUMINOID}}$ (D)	
Raw	Stored	Raw	Stored	Raw	Stored	Raw	Stored
0.690	0.329	5,419	2,129	436	256	231	21

Storage thus, on the average, more than halved the (A) and (B) ratios, nearly halved the (C) ratio and produced a ten-fold reduction in the (D) ratio ('traces' considered as 0.25).

These altered ratios consequent on storage depend, of course, on the modifications in the quality of the *raw* river water, and these modifications take time for their development. Inferentially, it would be quite possible from these ratios to gauge the probable 'safety' of a water from the bacteriological point of view, by correlating the time it takes to produce them with the time required for the destruction of pathogenic bacteria in water. The tendency in some quarters is rather to minimise the value of chemical tests in connection with water supply and the substances which pollute water, owing largely to the rapid strides made in bacteriology within recent years. But it is too often forgotten that, apart from the direct value of chemical tests, the only way of gauging the work done by bacteria may be by chemical analysis. Any process, method, or test which reveals an intrinsic modification in the quality of *raw* river water as the result of storage is both of direct and of inferential importance. That chemical analyses can achieve this end is indisputable.

Average number of microbes per cubic centimeter (bile-salt agar test)

RAW WATERS	STORED WATERS
River Thames......49.0	Walton..............1.6 (96.7 per cent reduction)
River Lee..........38.0	Lee (East London Aqueduct).........1.5 (96.1 per cent reduction)
New River......... 7.7	West Middlesex (1) .4.7 (90.4 per cent reduction)
	West Middlesex (3) .4.1 (91.6 per cent reduction)
	West Middlesex (4) .5.1 (89.6 per cent reduction)
	West Middlesex (6) .3.5 (92.9 per cent reduction)
	Lambeth (Island Barn)..............3.9 (92.0 per cent reduction)
	Sunbury.............6.3 (87.1 per cent reduction)
	New River (Clerkenwell)...............4.0 (48.1 per cent reduction)
	New River (Hornsey) 3.6 (53.2 per cent reduction)
	New River (Stoke Newington)........2.4 (68.8 per cent reduction)
	Grand Junction (Hampton).........2.4 (95.1 per cent reduction)
	Grand Junction (Kew).............5.2 (89.4 per cent reduction)
	Chelsea...............3.0 (93.9 per cent reduction)

(10) The use of stored water enables a *constant* check to be maintained on the safety of London's water antecedent to, and irrespective of filtration.

(11) The use of stored water goes far to neutralise or wipe out the gravity of any charge that a water supply is derived from polluted sources.

(12) The use of adequately stored water renders any accidental breakdown in the filtering arrangements much less serious than might otherwise be the case.

The storage of raw river waters has greatly reduced the load put upon filtration works. In 1910 it was calculated that 93.8 per cent of raw Thames samples showed B. coli present in 1 cc., in the case of the raw Lee, 95 per cent, and in the raw New River samples, 46.9 per cent. Studies of the stored pre-filtration waters showed that if they were all mixed in proportion to the amount used at the various filters about 37 per cent of all samples would show B. coli absent in 10 cc., that is, over one-third of such samples would be one hundred times better on the basis of the B. coli test.

The above table serves to indicate the reduction in excremental forms of bacteria, as determined by the bile-salt agar test at 37°C.

Circulation of water in storage reservoirs is discussed in the Twelfth Research Report. Several series of experiments were made with a view to determining the possibility of short circuiting in a reservoir where the position of inlet and outlet were favorable to this effect. The studies and conclusions of this work together with diagrams are a part of the résumé of the Fifteenth Annual Report.

SLOW AND RAPID SAND FILTRATION

Rapid sand filters have never met with general favor in England, probably because of the very excellent results achieved over a long period by the old slow sand filters, and also because of a fear that rapid filtration would prove more expensive and would bring about a situation, so far as water quality is concerned, which might prove to be epidemiologically unsafe. The London Water Board, however, has experimented with rapid filters since 1910 in both a small and a large way. Sir Alexander Houston has reported this work in the Thirteenth Annual and Thirteenth Research Reports together with very interesting deductions as to the practicability and advisability of using rapid filtration, either alone with or without coagulant, or as an adjunct to slow sand filtration. He has maintained an open mind on the subject, but it is evident from his writings that there is a strong sentiment in England which clings tenaciously to slow sand filtration, and that alone.

The successful use of chlorination has tended to weaken this sentiment, largely because it has shown new possibilities for rapid filtration as well as for the older form. Obviously costs as well as standards of safety have to be given careful consideration in any process of purification and these have been outside the main work of the London Laboratories. It may be of interest, however, to note that the cost of slow sand purification as practiced by the London Water Board is stated as 28 shillings per million Imp. gallons, of which

8 shillings is for operation and 20 shillings for capital charges. At normal exchange rates 28 shillings is the equivalent of $6.80. There seems to be some doubt that this cost can be met by rapid filtration if coagulant is used, unless rates of filtration are employed which imperil high standards of quality. It is admitted that the rapid mechanical filters would possess an economic advantage if coagulant was not used and very high rates were maintained, chlorination being employed to maintain bacteriological quality. Under such conditions, however, experiments indicated that there would be a marked falling off in the physical quality of the water as compared with the effluent of the slow sand process. Color would be increased somewhat and the colloidal suspended matter would be present in a sufficient amount to impart a dull look, destroying the "clean, polished" appearance of slow sand effluents. Brilliancy is recognized as one of the important physical properties of good drinking water, and Sir Alexander is of the same opinion as some of our American authorities that these physical properties must be preserved to meet the demands of the consumer.

The London Board has authorized the construction of rapid filters at Barn Elms and further experimental work at Staines with a view to their use as primary or prefilters. It is probable that future works will make use of this principle, thus utilizing both the slow and rapid processes of filtration and increasing considerably the existing rates of slow sand filters, which vary between 1,000,000 and 3,000,000 United States gallons per acre per day.

It is interesting to note that experimental filters of the rapid type, operating without coagulant and at rates of 125,000,000 to 250,000,000 United States gallons per acre per day, successfully removed over 80 per cent of the bacteria and nearly all plankton forms. The reduction in color was not as great as is obtained with slow sand filters, and there was not as complete removal of colloidal material. Effluent waters had the dull appearance noted above, a characteristic often noted in natural waters having some color and practically no turbidity.

EXCESS LIME AS A DISINFECTANT

Many who read this article will remember the experiments carried out at Columbus, Ohio, about 1912, which demonstrated the disinfecting power of caustic lime toward B. coli and fecal forms of bacteria. A marked reduction in the number of the organisms occurred if enough lime was added to neutralize the free CO_2, to precipitate the bicarbonates, and to leave an excess of several parts per million of caustic alkalinity. The practice was relied upon in one emergency, March, 1913, to disinfect the city mains after flood water had gained access to them by the washing out of a large main.

The Columbus work was suggested by the experiments originally carried out by the Laboratories of the Metropolitan Water Board which are described in the Eighth, Ninth, Tenth and Eleventh Research Reports. When this form of disinfection is made a supplementary part of water softening, it can be easily carried out and is fairly effective, for B. coli and kindred forms do not survive at hydrogen ion concentrations which are produced by caustic alkalinity. The process, however, will never supplant the more effective treatment of chlorination, which is also cheaper unless softening is the primary end sought.

A further sphere of application for this method of treatment, and one which has received but little notice, is that of controlling algae growths. Algae make use of CO_2 for food purposes and when this is exhausted have the power of decomposing bicarbonates. The writer has frequently found the surface water of Massachusetts ponds entirely devoid of free CO_2 and bicarbonates as a result of the growth of microscopic plant forms. If water is artificially softened to the same extent, then one of the most important food elements for algae is removed. The following quotation from the Fifteenth Annual Report indicates that excess lime has a practical field of usefulness in this direction.

> In 1917, Accra was faced with a very unsatisfactory position as regards its water supply. The water (swamp water, liable to pollution) deteriorated to a remarkable extend in the relatively large storage reservoirs, absolutely necessary for purposes of quantity. Exhaustive experiments were made, and it was found that by applying the 'excess lime' method of treatment the water was freed from excremental bacteria (e.g., B. coli) and remained clear, odourless, and free from growths under conditions of storage. The saving on alternative purification works represented a large sum of money. This is the first occasion on which the 'excess lime' method has been used for the express double purpose of destroying 'plankton' development and rendering water safe from the epidemiological point of view.

Other experiments with raw Thames water are reviewed to show the germidical effect of lime and suggested methods for "de-liming" or neutralization are given. These include the use of CO_2 from coke ovens, sodium bicarbonate, and the addition of unsoftened water which has been either stored or chlorinated. "In the use of Thames River Water about 67 per cent could be limed, and 33 per cent sterilized by means of hypochlorites, and the whole if mixed would be neutralized, sterilized and softened to the extent of about 16 parts per 100,000 parts (i.e., the hardness of the whole volume would be reduced about 71 per cent)." The expense of such treatment, in the case of a water as hard as the Thames, could only be justified on the grounds of economic saving through the use of softened water.

The experience of Aberdeen, which makes use of the soft water of the Dee, is also given. Liming was adopted as one of the three elements in a system of purification, the other two being storage and filtration. Proper disinfection was accomplished within seven days, using 10 parts per million CaO, of which only a small amount was in excess of that necessary for neutralizing CO_2 and bicarbonates.

In the same chapter various phases and fallacies of water softening as an economic asset are discussed in an interesting way.

STERILIZATION WITH CHLORINE AND HYPOCHLORITES

An alkaline solution of sodium hypochlorite containing 10 to 15 per cent of available chlorine was used in 1905 by Sir Alexander Houston to disinfect the Lincoln water supply. The results of this treatment, together with experiments on effluents of sewage works, are given in the Fifth Report of the Royal Commission on Sewage Disposal, Appendix IV. Further work with waters is described in the Twelfth and Thirteenth Research Reports and in the Eleventh, Twelfth, Thirteenth and Fifteenth Annual Reports of the Water Board. In the latter Sir Alexander takes the opportunity to sum up the advantages and disadvantages of chlorination, and to recall some of the objections on the ground of injury to health which were raised against the use of hypochlorites when he was a pioneer in this field in 1905 and "had to bear the full brunt of the well meant, but hostile, criticism of his professional brethren."

The London laboratories have done a great deal in times past to circumvent the persistence of after tastes and odors in chlorinated waters, taking as a basic principle the belief that the sentiment of consumers on this point, while not based upon injury suffered from the drinking of such waters, is nevertheless something to be respected and not laughed out of court. The latter view has too often been the one adopted in this country, but it is bound to yield as greater recognition is given to the importance of physical qualities. The practice of over-dosing was probably never carried to a more illogical end than it was in many cases with the American Expeditionary Forces in France. The notion that "if a little is good more is better" too often dominated the practice of water disinfection, particularly in Lyster bags. The result was a water of repugnant taste and odor, which defeated the real objects in view, namely, proper water discipline on the part of the troops and the consumption of adequate quantities of water. A more moderate dose, such as was applied at water stations having chlorinating apparatus, would have given the protection and would not have sent back to America some two million men with preconceived ideas as to the unfitness of chlorinated water for drinking purposes.

The work of Sir Alexander Houston with London waters led him to the conclusion that, with the exception of certain special cases where over-dosing is necessary, it was possible to produce a tasteless as well as a disinfected water, using either chloride or lime or liquid chlorine. He considers that the taste of chlorinated water is in the great majority of cases not chlorinous, but that it is the "iodoform" taste. The latter sometimes results when small but bacteriologically effective doses are used. It may be removed by the addition of potassium permanganate, or by the addition of more chlorine. Experiments recorded in the Thirteen Research Report indicate that potassium permanganate is effective in removing the "iodoform" taste from water originally dosed with 1 part in 1,000,000 of chlorine when applied in the proportion of 1 part in 5,000,000 up to 8 parts in 5,000,000, no samples retaining the taste with the larger dose. This is an expensive chemical, judged by market prices, but is one which does not permanently affect the physical quality of the water especially if filtration follows. With a dose as large as 1 part in 1,250,000 a pink tinge persisted for several hours, followed by the brown precipitate of oxide which might require filtration.

If chlorine was added to remove an "iodoform" taste already formed or to prevent its forming, a chlorinous taste was likely to develop. This was less unpleasant than the "iodoform" taste and was capable of removal by dechlorination, using some substance as sulphur dioxide or sodium thiosulphate.

Waters differed in their ability to produce one or the other taste. In some it was difficult if not impossible to develop the "iodoform" taste. Without the latter a chlorinous taste did not develop until a residual dose of 0.27 to 0.90 part per million of chlorine remained. The various relations are best indicated by quoting from the Fifteenth Annual Report.

> The following provisional conclusions, subject to any reservations previously made, seem to be justifiable:
>
> *Relation of chlorine to chlorinous taste.*
>
> Huge doses with de-chlorination, *no* taste.
>
> Doses of about 1 in 1 million (upwards) without de-chlorination, chlorinous taste.
>
> *Relation of chlorine to "iodoform" taste (when present).*
>
> After de-chlorination, still an "iodoform" taste.
>
> After super-dosing with chlorine, no "iodoform," but chlorinous taste.
>
> After super-dosing with chlorine and dechlorinating, neither an "iodoform" nor a chlorinous taste.
>
> *Relation of permanganate to taste.*
>
> In small doses, even without sulphite treatment, *no* taste.
>
> In huge doses, after sulphite treatment, *no* permanganate taste.
>
> *Relation of chlorine, permanganate and filtration to "iodoform" taste, it being assumed that without the permanganate the "iodoform" taste occurs.*
>
> First chlorination, then permanganate treatment and lastly filtration, *no* "iodoform" taste.
>
> First permanganate treatment, then chlorination and lastly filtration, *no* "iodoform" taste.
>
> Chlorination and permanganate treatment simultaneously and then filtration, *no* "iodoform" taste.
>
> First chlorination, then filtration and lastly permanganate treatment, *no* "iodoform" taste.
>
> First filtration, then chlorination and lastly permanganate treatment, *no* "iodoform" taste.
>
> First filtration, then permanganate treatment and lastly chlorination, *no* "iodoform" taste.
>
> First filtration, then chlorination and permanganate treatment simultaneously, *no* "iodoform" taste.
>
> First permanganate treatment, then filtration and lastly chlorination, "*iodoform*" taste.

Successful chlorination of Thames River water at Staines has been practiced since 1916, using bleach at a rate of about 0.4 part per million of chlorine. This installation has effected a great saving in pumping costs by making it possible to let the chlorinated water flow down the Staines aqueduct to numerous works below without being pumped to the Staines reservoirs for storage. Water of greater bacteriological purity has been delivered to these works than when stored water was used, and there has been a reduction of something like 20 per cent in the acreage of filter beds cleaned. The latter is attributed to the mild algacidal action of chlorine and the elimination of growths which develop with storage. At the same time there has been no complaint of tastes due to chlorination. About 2,000,000 people have been served with this water the volume of which amounts to 76,000,000 Imperial gallons daily.

PERIOD	CHLORINE				PERMANGANATE			
	Days	Water treated	Chlorine used	Average dose	Days	Water treated	$KMnO_4$ used	Average dose
		*m. g.**	*lbs.*			*m. g.*	*lbs.*	*lbs. per m. g.*
First	17	560	1,830	1 in 3.06M	4	132	264	2.00
Second	12	390.1	891	1 in 4.38M	0	0	0	
Third	49	1637.6	4,790	1 in 3.42M	9½	317.4	627	1.98
Total	78	2587.7	7,511	1 in 3.45M	13½	449.4	891	1.98

First period = April 12 to 29, 1920.
Second period = December 3 to 15, 1920.
Third period = December 29, 1920, to February 16, 1921.

Average supply per day........................33.2 million gallons
Average dose of chlorine, 1 in 3.43 millions, or 2.9 lbs. per million gals.
Number of days of permanganate treatment, 13½ or 17.3% of whole.
Cost of chlorine..4d. per lb.
Cost of permanganate....................................3s. per lb.

	£	*s.*	*d.*
Total cost of chlorine	125	3	8
Total cost of permanganate	133	13	0
Total cost of chemicals	£258	16	8

Total cost of chemicals per million gallons treated, 2s.

*Imperial gallon used. Equals 1.2 U. S. gallons.

During a part of the year the water of the New River is treated with liquid chlorine at Highfield on its way to the Hornsey and Stoke Newington reservoirs. A dose of 1 part in 4,000,000 or 5,000, 000 is normally added and this is gradually increased, as the turbidity rises in flood time, to about 1 part in 2,000,000. With the maximum dose permanganate is added in the proportion of 2 to 8 pounds per million Imperial gallons in order to prevent tastes. Below, at Wood Green, is a dechlorinating plant where SO_2 is added at certain times when the chlorine dose is high and the water cold. Daily tests are made to facilitate the control of tastes. The treatment has been very successful, both from the bacteriological standpoint and that of the absence of residual tastes. For example, out of 260 cultures of raw water taken in the cold months at Highfield before chlorination 82.3 per cent contained B. coli in 1 cc. A similar number at Wood Green after treatment showed B. coli absent in 96.5 per cent of 10 cc. portions. The above table is of interest in connection with the operation of this chlorine installation.

It should be remembered that the object of chlorination of these London waters has not been the attainment of the highest bacterial standard by this treatment alone, but rather an improvement in the quality of waters delivered to existing purification works with a view to relieving the load put upon them and obtaining a final product which will measure up to high standards.

If space permitted, much more could be written by way of comment and review of the highly interesting and valuable studies which have been carried out by the Laboratories of the Metropolitan Water Board. The preparation of this paper has been an instructive and pleasant task, and the author recommends the various reports for the further perusal of all who are interested in the historical and professional aspects of water purification during the past fifteen years. It is to be regretted that more files of these are not available for study. There is much that is stimulating as well as instructive within their pages.